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# Remote Station User's Guide

by John T. Clark

ARL-TR-4449 May 2008

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# Remote Station User's Guide


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## Introduction

The Millimeter Wave Branch of the Army Research Laboratory has developed a Remote Station (RS) that operates in a portion (33.2 GHz to 36.4 GHz) of the Ka Frequency Band to be used as a transponder (transmitter-responder) to simulate radar target returns with the following attributes: Radar Cross Section (RCS) and Doppler Frequency Shift. The Doppler Shift settings are controlled by a single board computer (SBC) which is resident in the RS. The user interfaces with the SBC via a standard laptop serial (RS-232) interface. Simulated RCS is determined by the setting of a manual (rotary knob) variable attenuator. This guide will describe in detail the operation and procedures for configuration of the RS.

## RF Architecture

The schematic diagram of the RS is shown in figure 1. Note that several power dividers are in place with only one output in use. This signifies legacy hardware that is no longer in use but remains present to maintain proper power levels. There are two sections, the Local Oscillator (LO) Section and the Radio Frequency (RF) Section as shown in figure 1.

The LO Section starts with the master oscillator (an oven controlled 400 MHz crystal oscillator). As shown in the schematic, this signal is manipulated to obtain a 2.8 GHz signal and a 200 MHz reference. The reference is used by a Direct Digital Synthesizer (DDS) which produces output signals ranging from DC to 1 MHz in both In-Phase (I) and Quadrature-Phase (Q) outputs. The DDS is controlled by a resident SBC which the user interfaces with via a standard RS-232 serial interface. Details of this control interface will be provided later. The DDS output represents the synthetic Doppler offset frequency ($f_d$) the RS is to emulate. The DDS I&Q outputs are sent to a single sideband modulator where they are added onto the previously mentioned 2.8 GHz carrier (this modulator output is denoted LO#2). An unadulterated version of the 2.8 GHz carrier is also available (this pure carrier is denoted LO#1). Thus, the LO Section has synthesized the two LO signals needed by the RF Section: (1) 2.8 GHz and (2) 2.8 GHz+ $f_d$. The user determines the value of $f_d$ as discussed later.

The RS is a transponder which indicates that it will not transmit a signal unless it has received one in the appropriate frequency and power range. Filters shown in figure 1 effectively limit the acceptable bandwidth to 33.2 GHz to 36.4 GHz. As with any RF system, there are non-linear devices in use which exhibit power compression. These devices will exhibit a 1 dB gain decrease (or 1 dB conversion loss increase) when certain power levels are met or exceeded. Operation in this region is not desired since signal distortion may occur as well as an inadvertent lowering of system gain which will alter the simulated RCS. Compression measurements have

been performed on the RS for this frequency band, revealing that the input power level should be less than –35 dBm to prevent power compression.

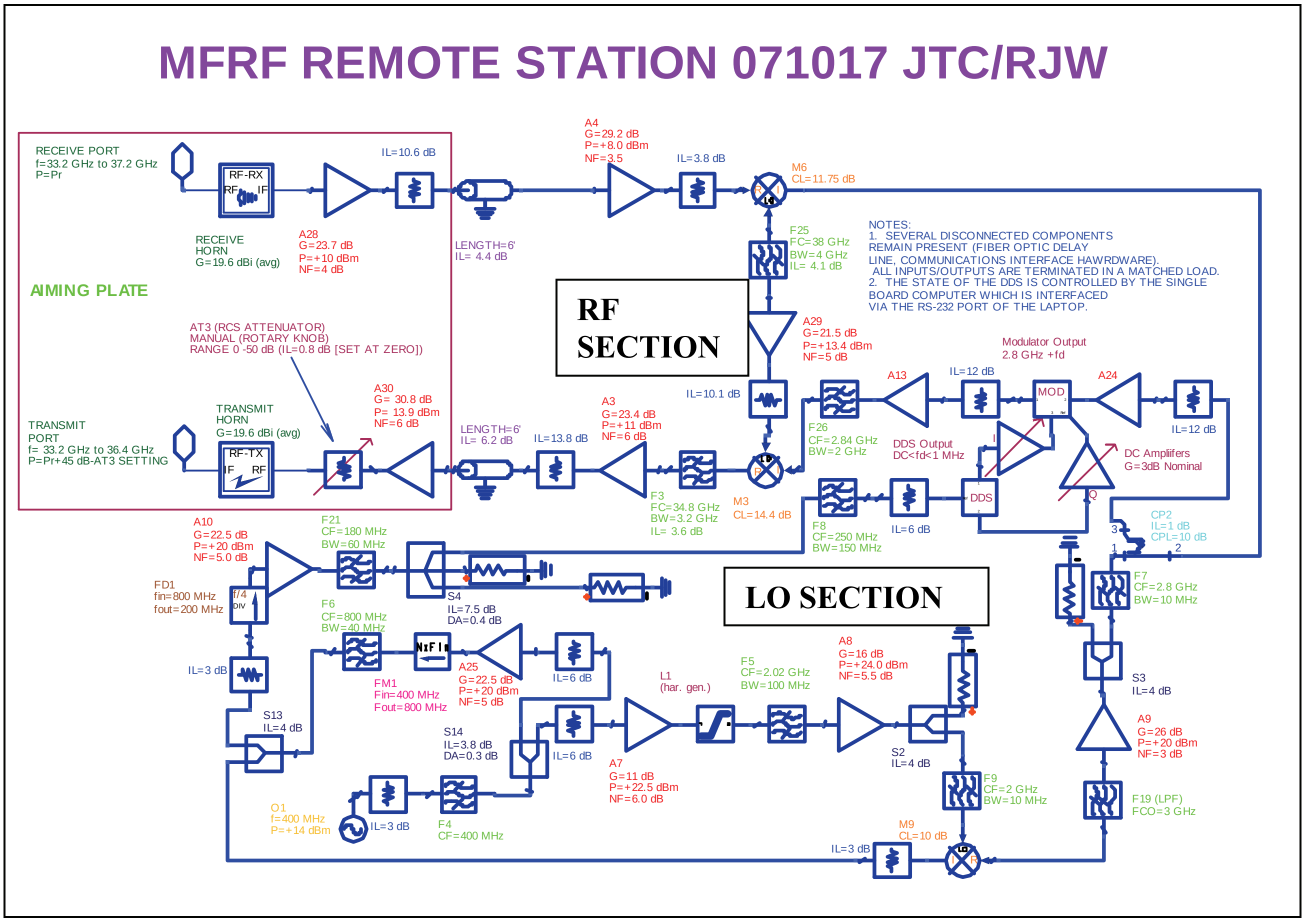


Figure 1. Remote station (RS) schematic diagram.

To facilitate aiming of the RS input to a remote radiation source, some front-end hardware has been relocated to an aiming plate. This plate is denoted in figure 1 as the items enclosed by the rectangle. After reception of a radiation source by the standard gain horn antenna (G~19.8 dBi), the received signal is amplified and sent via coaxial cable to the main RS assembly where it is up-converted (by LO#1 of 2.8 GHz) to 36 GHz to 39.2 GHz. This Intermediate Frequency (IF) is then down-converted (by LO#2 of 2.8 GHz $+f_d$) back to 36 GHz to 39.2 GHz minus the Doppler shift (the "minus" shift is the result of performing a down-conversion on the signal). This Doppler sign represents a closing target. Finally, this signal is transported back to the aiming plate via coaxial cables where it is amplified and presented to a manual variable attenuator (AT3) which will determine the value of simulated RCS. The next section will describe in detail how AT3 is utilized in the determination of simulated RCS.

## Derivation of Simulated Radar Cross Section

In this section, a derivation of the expression for simulated RCS as a function of wavelength, RS antenna gain and system (RF) gain of the RS will be performed. As discussed above, the input power into the RF Section (after reception by the RS Receive Antenna) should be less than –35 dBm. Failure to limit the power level in this manner will compress the RS Gain and thus alter the simulated RCS as described below. The user should calculate an expected input power level as given by equation 2 below which is a function of source power, source transmit antenna gain, the range between the source and the RS and the Gain of the RS Receive Antenna. This value should not exceed the maximum input power of the RS which is less than or equal to –35 dBm. Refer to the *Operating Instructions* section for detailed instructions on calculating a safe minimum distance between the RS and the user's radiation source.

Consider the case shown in figure 2, where a radar system generates a Power level, $P_t$, which is presented to a directive transmit antenna with Gain, $G_t$.

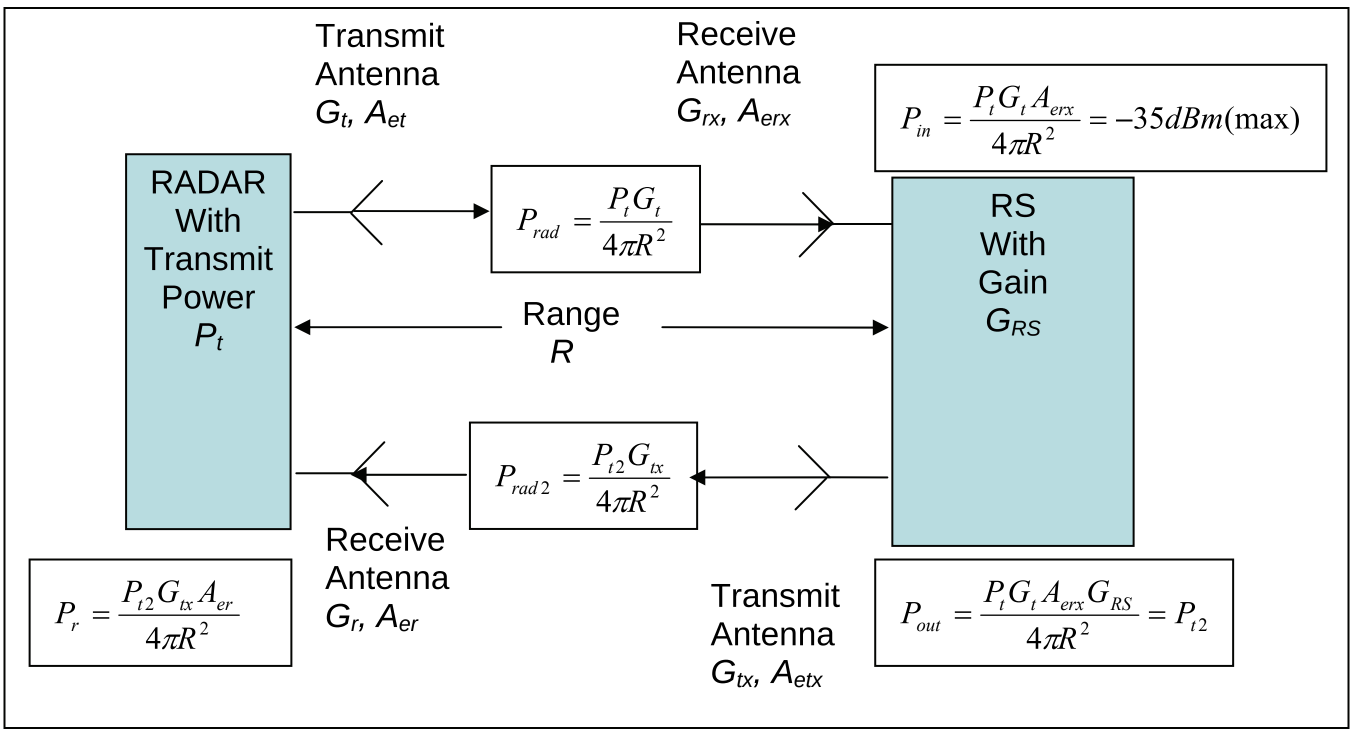


Figure 2. Radar and remote station (RS) setup.

The radiated power density, $P_{rad}$, is given by equation 1.

$$P_{rad} = \frac{P_t G_t}{4\pi R^2} \qquad \text{(W/m}^2\text{)} \qquad (1)$$

This radiated power is received by the RS receiver antenna's effective aperture, $A_{erx}$, and it is the input power, $P_{in}$, to the RS, given by equation 2. Recall that this value must not exceed –35 dBm.

$$P_{in} = \frac{P_t G_t A_{erx}}{4\pi R^2} \qquad \text{(W)} \qquad (2)$$

This signal's power is increased by the gain of the RS, $G_{RS}$, and is given by equation 3.

$$P_{out} = P_{in} G_{RS} = \frac{P_t G_t A_{erx} G_{RS}}{4\pi R^2} = P_{t2} \qquad \text{(W)} \qquad (3)$$

This signal is now presented to the RS Transmit Antenna and is denoted for convenience as $P_{t2}$. Just as in equation 1, another radiated power density (denoted as $P_{rad2}$) is created, in this case via the RS transmit antenna, which has a gain, $G_{tx}$ , as in equation 4.

$$P_{rad2} = \frac{P_{t2} G_{tx}}{4\pi R^2} \qquad (\text{W/m}^2) \qquad (4)$$

Finally, $P_{rad2}$ is received through the radar's receive antenna's effective aperture, $A_{er}$, and listed as a received power, $P_r$, as in equation 5.

$$P_r = \frac{P_{t2} G_{tx} A_{er}}{4\pi R^2} = \frac{P_t G_t A_{erx} G_{tx} G_{RS} A_{er}}{(4\pi R^2)^2} \qquad \text{(W)} \qquad (5)$$

Now consider a true target at a distance $R$, using the same radar system as in figure 1, with an RCS, $\sigma$. Skolnik[1] derives the power received from such a target as in equation 6.

$$P_r = \frac{P_t G_t A_{er} \sigma}{(4\pi R^2)^2} \qquad \text{(W)} \qquad (6)$$

Setting equations 5 and 6 equal to each other, as in equation 7a, we can solve for σ as in equation 7b after common terms are removed.

$$P_r = \frac{P_{t2} G_{tx} A_{er}}{4\pi R^2} = \frac{P_t G_t A_{erx} G_{tx} G_{RS} A_{er}}{(4\pi R^2)^2} = P_r = \frac{P_t G_t A_{er} \sigma}{(4\pi R^2)^2} \qquad \text{(W)} \qquad (7a)$$

$$\sigma = A_{erx} G_{tx} G_{RS} \qquad (\text{m}^2) \qquad (7b)$$

Equation 7b shows that simulated RCS only depends on the gain of the RS, the gain of the RS transmit antenna and the effective aperture of the RS receive antenna. Thus, it is independent of radar transmitter power, range or type of antennae used at the radar. It is implicitly dependent on the frequency just as true RCS is (since antenna gain and effective aperture are functions of wavelength). As mentioned above, $G_{RS}$ will be less than expected if the input power is equal to or greater than –35 dBm.

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[1]Skolnik, M. I., Introduction to Radar Systems, p. 4, McGraw Hill, 1980.

If the two RS antennae are identical (which is usually the case), equation 7b can be rewritten as

$$\sigma = 4\pi G_{RS}\left(\frac{A_{eRS}}{\lambda}\right)^2 \qquad (m^2) \qquad (8a)$$

$$\text{or} \quad \sigma = \frac{G_{RS}}{4\pi}\left(G_{RS\_ANT}\lambda\right)^2 \qquad (m^2) \qquad (8b)$$

where $G_{RS\_ANT}$ and $A_{eRS}$ are the gain and effective aperture of the identical transponder antennae respectively, since[2]

$$G = \frac{A_e 4\pi}{\lambda^2} \qquad (9)$$

As an example, consider the RS with a gain of 45.5 dB ($P_{in}$=–40 dBm) which uses two identical horn antennae with a gain of 19.5 dBi at 33.575 GHz. The calculation of simulated RCS is as follows:

$$\lambda = \frac{c}{f} = \frac{3*10^8\ m/s}{33.575*10^9\ Hz} = 8.94*10^{-3}\ m \qquad \begin{aligned} G_{RS} &= 45.5\ dB = 35{,}481.3:1 \\ G_{RS\_ANT} &= 19.5\ dBi = 89.1:1 \end{aligned}$$

$$\sigma = \frac{35{,}481.3:1}{4\pi}\left(89.1:1*8.94*10^{-3}\ m\right)^2 = 1{,}790.6\ m^2 = +32.53\ dBsm\,.$$

This is the maximum RCS that can be simulated by the RS and corresponds to the manual variable attenuator (RS AT3) being set to 0 dB. The RCS Attenuator has calibrated attenuation values between 0 and 50 dB therefore the calibrated RCS can range from the above mentioned maximum value of +32.73 dBsm to –17.27 dBsm (for f=33.575 GHz). There is also an uncalibrated region between 50 dB past a point denoted "MAX" to a hard stop where AT3 delivers even more attenuation than 50 dB. It should be noted that once the setting of AT3 exceeds the RS Gain of 45.5 dB the overall noise figure of the RS will be more directly degraded by the setting of AT3.

It is important to note that the RCS will vary with frequency. A natural target will exhibit an increase in RCS with an increase in frequency. However, our synthetic target differs from this phenomenon. This deviation is due to the fact that the RF Gain of the RS is not constant with respect to frequency nor is it monotonic. Figure 3 is a plot of the RS Gain versus frequency measured by the author on 10/15/07 using a Wiltron 32796A Vector Network Analyzer. Appendix A lists the data points for this plot (data collected every 20 MHz).

[2]Skolnik, M. I., Introduction to Radar Systems, p. 4, McGraw Hill, 1980.

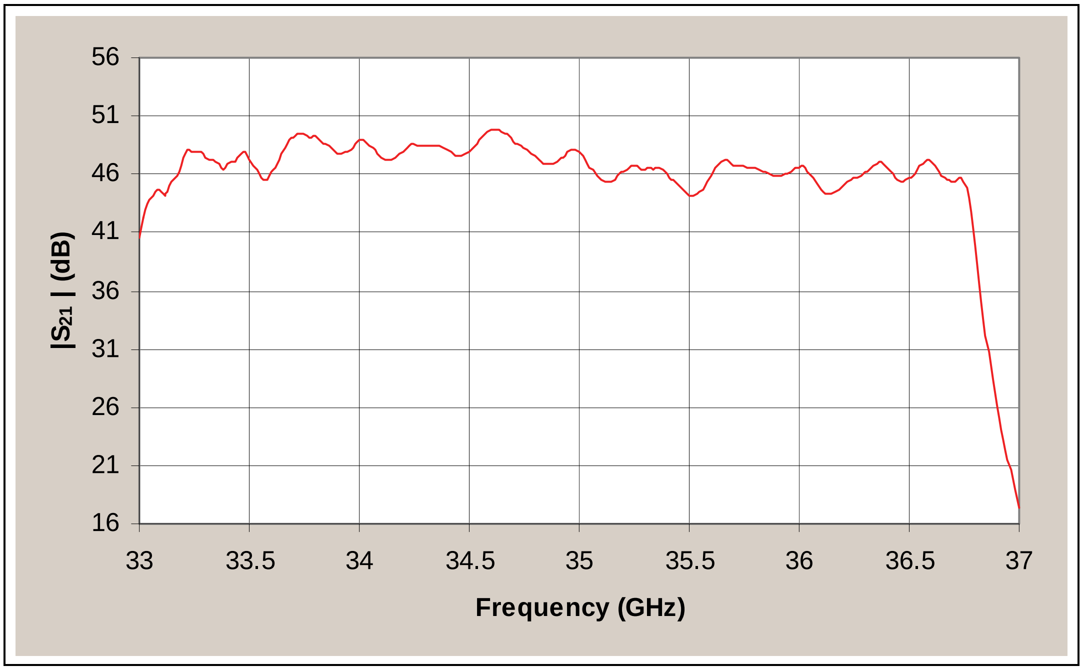


Figure 3. Measured gain of remote station.

To illustrate the variation of simulated RCS due to RS Gain ripple, the above example is repeated for an operating frequency of 34.7 GHz where the gain of the RS antennae have increased to19.8 dBi and the RS Gain has increased to 48.8 dB:

$$\lambda = \frac{c}{f} = \frac{3*10^8\ m/s}{34.7*10^9\ Hz} = 8.65*10^{-3}\ m \qquad \begin{aligned} G_{RS} &= 48.8\ dB = 75{,}857.76:1 \\ G_{RS\_ANT} &= 19.8\ \ dBi = 95.5:1 \end{aligned}$$

$$\sigma = \frac{75{,}857.76:1}{4\pi}\left(95.5:1*8.65*10^{-3}\ m\right)^2 = 4{,}115\ m^2 = +36.14\ dBsm$$

Note that this simulated RCS varies by 3.61 dB from the previous example. The gain has increased by 3.3 dB which shows that for a constant gain, the simulated RCS would have only increased by 0.31 dB (similar to the natural increase of a "true" target).

Table 1 lists the parameters used in equation 8b to calculate maximum simulated RCS for selected frequencies of interest. This maximum value is achieved when AT3 is set to an attenuation value of 0 dB. The change in simulated RCS is directly proportional to RS Gain as shown in equation 8b, which implies that for every dB increase in the attenuation value of AT3 (which is a dB decrease in $G_{RS}$) there is a corresponding dB decrease in simulated RCS. For example, if the user desires to simulate +10 dBsm at 33.575 GHz, $G_{RS}$ must be reduced by 22.53 dB (=32.53-10) which is accomplished by setting AT3 to 22.53 dB (such precision is not possible so a setting of 22.5 dB would have to suffice).

Table 1. Maximum simulated RCS for selected frequencies.

| Frequency (GHz) | $\lambda$ (mm) | $G_{RS\_ANT}$ (dBi)* | $G_{RS}$ (dB) | $\sigma_{MAX}$ (dBsm) |
|---|---|---|---|---|
| 33.575 | 8.94 | 19.5 | 45.5 | 32.53 |
| 34.7 | 8.65 | 19.8 | 48.8 | 36.14 |
| 35.825 | 8.37 | 20.1 | 46.3 | 33.96 |

*Accuracy of Antenna Gain Measurements is limited to ±0.5 dB due to alignment errors and tolerance of Calibrated Gain (Reference) Antenna.

Table 1 illustrates the effect of RS Gain ripple on maximum simulated RCS. Note that as the frequency increases from 34.7 GHz to 35.825 GHz the maximum simulated RCS actually decreases from 36.14 dBsm to 33.96 dBsm (decreased by 2.18 dB). Also note the gain is also decreased from 48.8 dB to 46.3 dB (decreased by 2.5 dB). Thus, if the gain were constant the simulated RCS would have actually increased by 0.32 dB (again similar to the natural increase of a "true" target).

If the user desires, the gain ripple may be removed by applying an initial value to AT3 which would change $G_{RS}$ to 45.5 dB. For example if operation at 35.825 GHz is desired an initial attenuation value of 0.8 dB should be set on AT3. This would reduce $G_{RS}$ to 45.5 dB and change $\sigma_{max}$ to 33.16 dBsm (recall that for constant gain, $\sigma_{max}$ still increases by a small amount). Care must be exercised to remember the initial value when determining future settings for RCS reduction. As an example, suppose the user desires to simulate 0 dBsm at 34.7 GHz using the above discussed gain ripple removal technique. The gain is 3.3 dB higher than the reference value at 33.575 GHz (this frequency is chosen as the reference since it has the lowest gain), thus AT3 should be set to 3.3 dB. This will reduce $G_{RS}$ to 45.5 dB and via equation 8b $\sigma_{max}$ would equal 32.84 dBsm. To achieve a simulation of 0 dBsm, $G_{RS}$ must be reduced by 32.84 dB, which is accomplished by setting AT3 to a value of this desired decrease *plus* the initial value. In this case that value is (32.84+3.3=) 36.14 dB. Once again that level of precision is not possible with AT3 so a setting of 36 dB will have to suffice.

Maximum Simulated RCS may be calculated for any frequency the user desires by using equation 8b. To determine the correct value of $G_{RS}$ to use, consult the appendix which lists the measured values of $G_{RS}$ from 33 GHz to 37 GHz in 20 MHz increments. To calculate the correct value of $G_{RS\_ANT}$, equation 9 can be used to solve for the constant value of the Antenna Effective Aperture ($A_e$) when the Gain and wavelength are known. Use this constant value (in the case of our RS Receive Horns, $A_e$=5.66 * $10^{-4}$ $m^2$) with the new wavelength corresponding to the new frequency of interest to calculate the new $G_{RS\_ANT}$ in equation 9.

## Operating Instructions

The RS is housed in a white portable rack enclosure which is weatherproof when the both front and rear doors are attached. Figure 4 is a photograph of the RS in its transit/storage state.

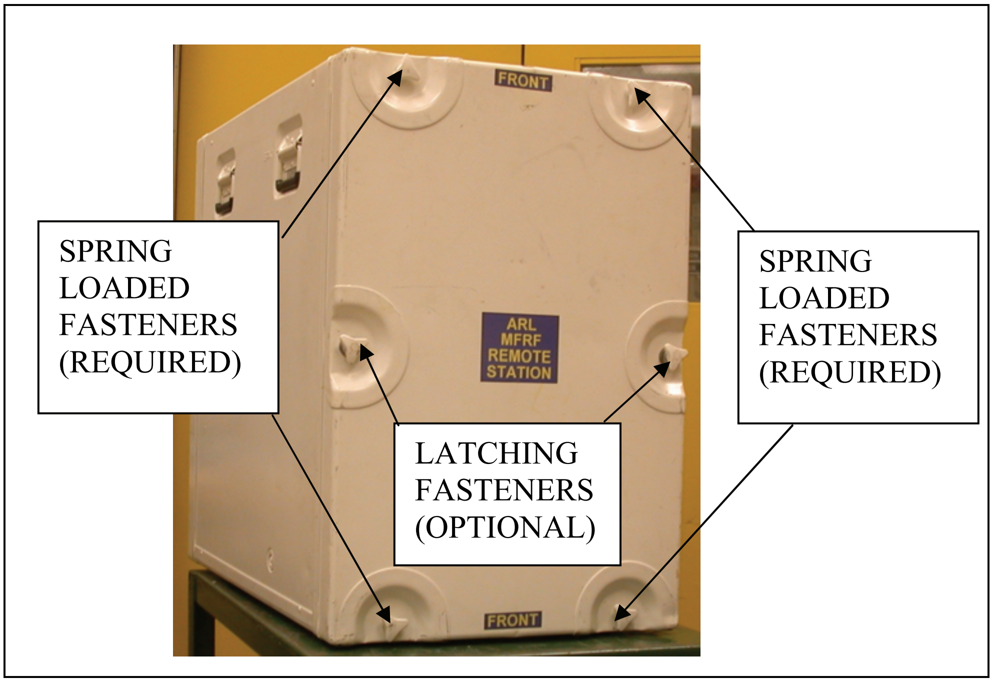


Figure 4. Remote station in transit/storage state.

Located at the four corners of the front and rear doors are spring loaded fasteners which seal the doors to the enclosure creating the weatherproof condition. These fasteners must be completely tightened to ensure a weatherproof seal and/or secure shipping mode. There are also two latching fasteners on the center sides of each door which provide an extra layer of closure. Engaging these latching fasteners is not required.

The RS has a total weight of 154 lbs. When moving the RS manually, two persons are required to lift the unit using the side handles shown in figure 4. The task is simplified when four persons each use a handle and position the RS in place. Be sure to face the “FRONT” of the RS towards the source of RF Radiation.

To verify a safe range of operation, consider the scenario illustrated in figure 5.

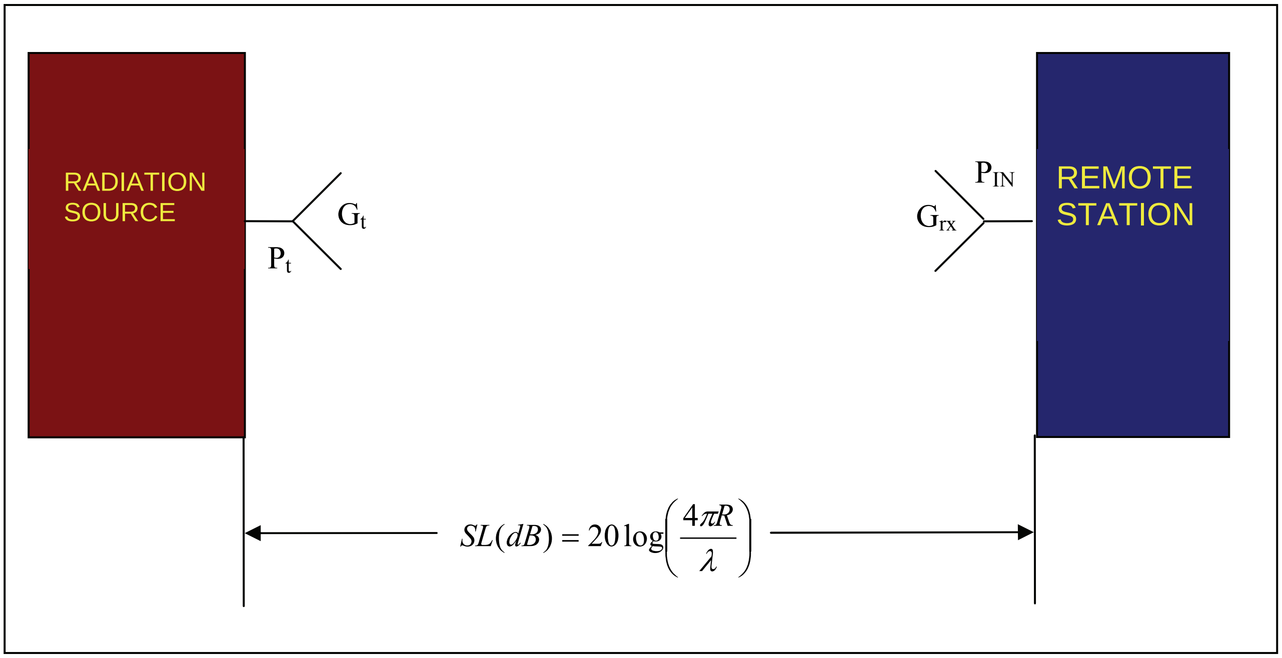


Figure 5. Field test setup to determine minimum range.

The radiated signal will endure space (or path) loss as it travels through the atmosphere. This space loss, ($SL$), is defined by Wolff & Kaul[3] as

$$SL(dB) = 20\log\left(\frac{4\pi R}{\lambda}\right) \qquad \text{(dB)} \qquad (10)$$

The two antenna gains shown in figure 4 reduce the Space Loss encountered by directing (pointing) the energy in a certain direction. When the two antennae are aimed at each other, the actual loss is then the sum of the Gain of the Transmit Antenna ($G_t$) in dBi and the Gain of the RS Receive Antenna ($G_{rx}$) in dBi less the Space Loss ($SL$) in dB. The input Power to the RS, $P_{IN}$, would then be the amount of Power Transmitted, $P_t$ (in dBm), less the actual loss and is given by equation 11:

$$P_{IN} = P_t + G_t - SL(dB) + G_{rx} \qquad \text{(dBm)} \qquad (11)$$

Recall that $P_{IN}$ must be less than or equal to –35 dBm to prevent the RS from exhibiting gain compression which sets up a maximum input power level condition. This condition has a corresponding minimum range, $R_{min}$, which will be derived at this point.

Equation 11 can be solved for SL(dB) as in equation 12:

$$SL(dB) = P_t - P_{IN} + G_t + G_{rx} \qquad \text{(dB)} \qquad (12)$$

Setting equations 12 and 10 equal to each other yields:

[3]Edward A. Wolff & Roger Kaul, Microwave Engineering and Systems Applications, p. 26, John Wiley & Sons, 1988.

$$20\log\left(\frac{4\pi R}{\lambda}\right) = P_t - P_{IN} + G_t + G_{rx} \qquad \text{(dB)} \qquad (13)$$

Equation 13 can be solved for R as follows:

$$R = \frac{\lambda}{4\pi}\left[10^{\left(\frac{P_t - P_{IN} + G_t + G_{rx}}{20}\right)}\right] \qquad \text{(m)} \qquad (14)$$

Setting the maximum input power, $P_{IN}$, equal to the maximum value of –35 dBm allows the use of equation 14 to calculate, $R_{min}$ as shown in equation 15.

$$R_{\min} = \frac{\lambda}{4\pi}\left[10^{\left(\frac{P_t + 35\ dBm + G_t + G_{rx}}{20}\right)}\right] \qquad \text{(m)} \qquad (15)$$

For example, consider a radiation source operating with 150 W of output power, a Transmit Antenna with 42 dBi of Gain at 34.7 GHz the determination of $R_{min}$ is as follows:

1. From Table 1, $G_{rx}$ is 19.5 dBi
2. Transmit Power=150 W=150,000 mw=>$P_t$=10log(150,000 mw)=+51.76 dBm
3. $\lambda$=c/f=(3*10$^8$ m/s)/(34.7 GHz)=8.65*10$^{-3}$ m
4. Substituting these values into equation 15 gives:

$$R_{\min} = \frac{8.65*10^{-3}\,m}{4\pi}\left[10^{\left(\frac{51.76dBm + 35\ dBm + 42dBi + 19.5dBi}{20}\right)}\right] = 17{,}806.64\text{ m} = 17.8\text{ km}$$

Thus, the RS should be at least 17.81 km from the radiation source in this example to prevent gain compression. If this is not possible, the user can either (1) reduce the amount of transmit power or (2) reduce the link gain by misaligning the RS antenna and that of the source transmit antenna (aim-off).

Once a safe location has been determined as described above, the RS may be positioned. The RS may be placed directly on the ground, however, it is recommended that if wet (swampy) conditions are expected that the unit be placed on a structure to elevate it such that the possibility of ground water flooding the bottom of the enclosure (where the power supply is located) is eliminated.

Remove each door by rotating the latching fasteners (if engaged) and the spring loaded fasteners counterclockwise (to the left) until the door is free of all connections. The doors may be stored on the ground provided that the inside of the door is not susceptible to collecting ground water. When reattaching the doors, check that the inside of the doors are free of debris (sand, dirt,

insects, grass, etc.) and moisture. Avoid placing heavy items on the doors when they are removed as this may bend the doors such that they can not be reattached. Figure 6 contains photographs of the interior of the enclosure showing the frontal view in figure 6(a) and the rear view in figure 6(b) with key user interfaces highlighted. The locking clips shown in figure 6(a) are required to prevent the RF Deck and Power Supply Decks from sliding out. If service is required, these locking clips must be removed.

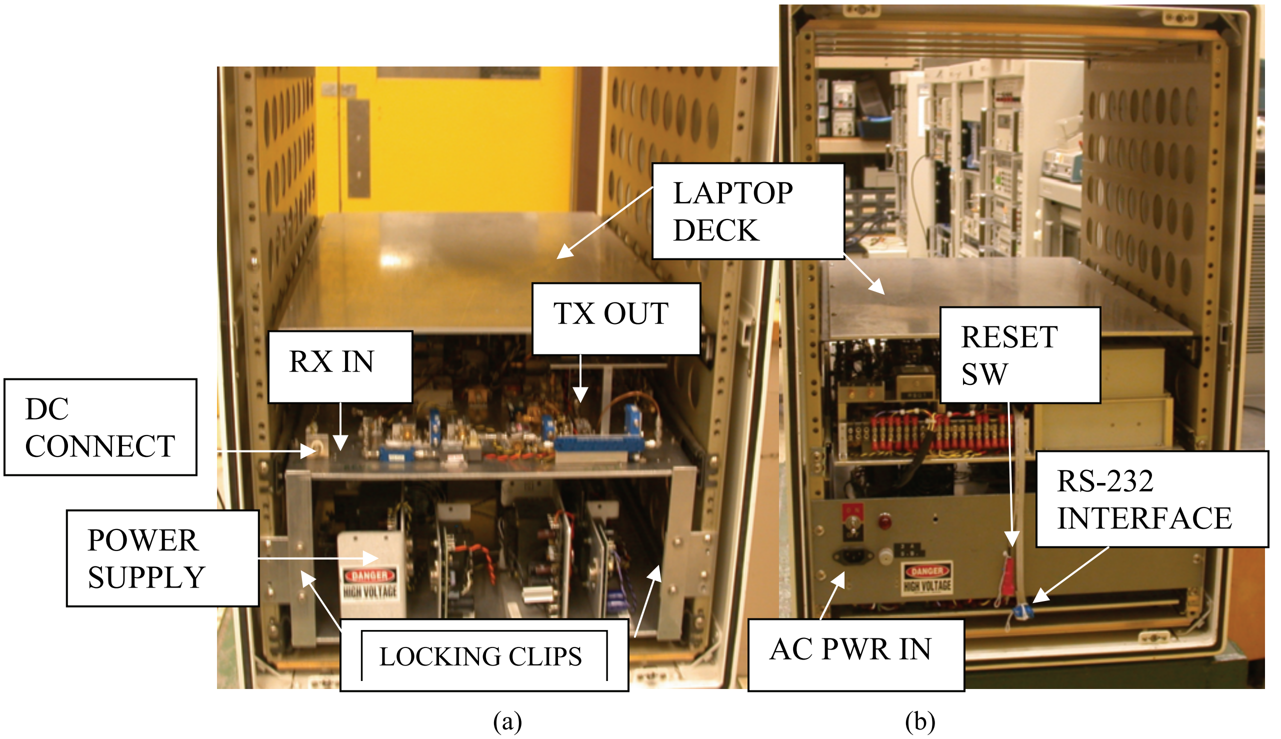


Figure 6. (a) Frontal view of the RS (b) rear view of the RS.

Figure 7 is a photograph of the Aiming Plate.

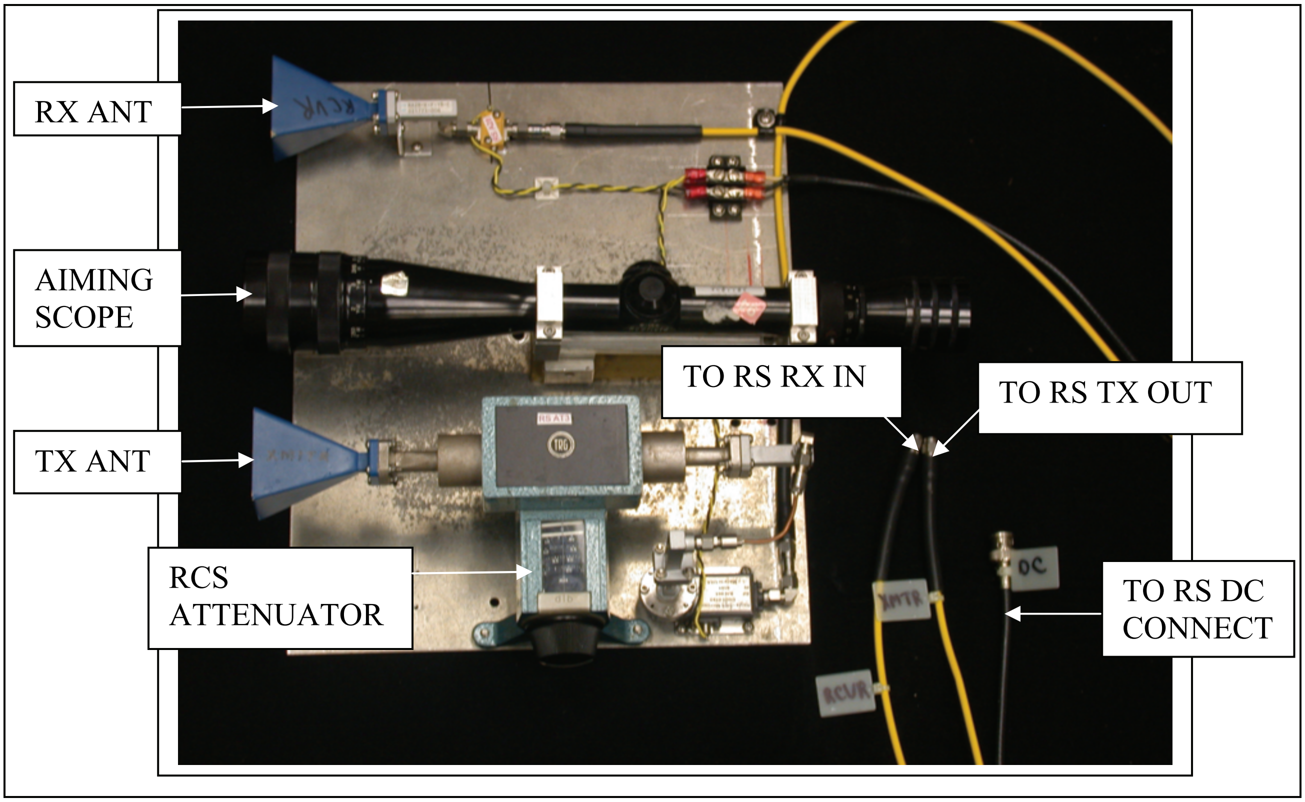


Figure 7. Remote station aiming plate.

Mount the aiming plate on a tripod and use the aiming scope to align the antennae with the radiation source. Connect the yellow coaxial cable labeled “RCVR” to the RX IN coaxial connection inside the RS chassis (left side as highlighted in figure 6(a)). Connect the yellow coaxial cable labeled “XMTR” to the TX OUT coaxial connection inside the RS chassis (right side as highlighted in figure 6(a)). Connect the BNC Cable labeled “DC” to the RS DC Connect (a BNC Jack highlighted on the right side of figure 6(a)). When these connections are completed, figure 6(a) should now resemble figure 8.

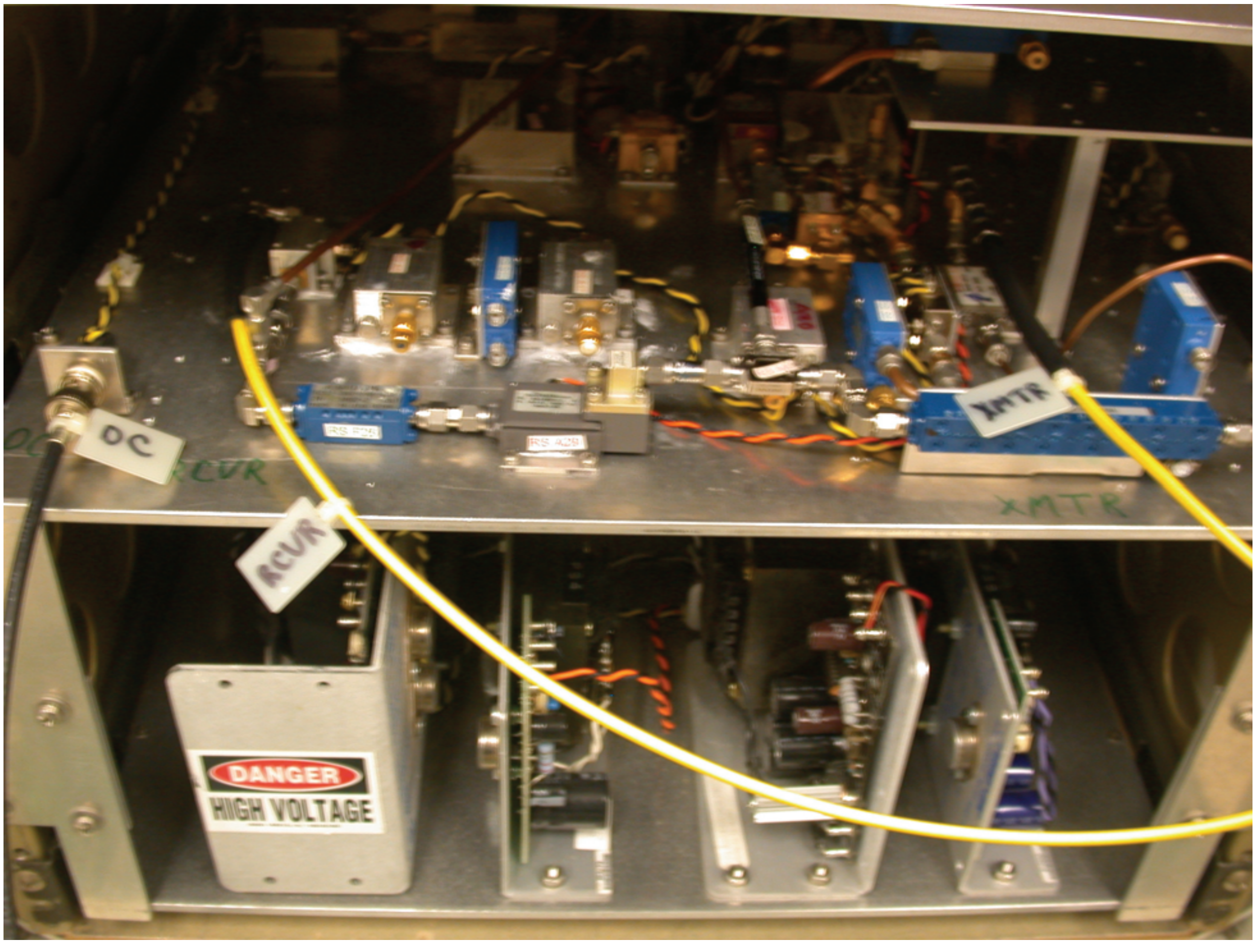


Figure 8. RF deck with aiming plate connections in place.

Connect a standard AC Line Power Cord to the AC Receptacle shown in figure 6(b). Make sure the power switch is in the OFF position and then plug the other end of the AC Line Power Cord into standard US AC Voltage (120 VAC rms). If you are planning to power the RS from a generator, it is recommended that you use the supplied Uninterruptible Power Supply (UPS) between the generator and the RS, as any fluctuation in line voltage will likely cycle the RS power supplies causing the SBC to reset to its default values without any indication to the user that this has occurred. Be sure to connect to the plugs on the side of the UPS labeled "Battery Backup plus Surge Protection" as the opposite side does not provide battery backup. Move the Power Switch to the ON position. The red power indicator should now be illuminated and the user should be able to hear the power supply fans operating. The Level Variable Attenuators will also "CLICK" upon power-up. If these conditions do not occur, check the status of the fuse (a slow acting 3A device) and replace if required.

Locate (shipped separately) and unpack the RS Laptop and check to make sure all components shown in figure 9 are present. Connect the RS-232 extender cable to the Serial Port (on the rear of the laptop) and to the input RS-232 port of the SBC as shown in figure 10. It is recommended

to use the AC Power Adaptor to power the Laptop, if feasible, so that the battery may be kept fully charged. However, the laptop may be operated solely from its internal battery until the battery is depleted. If this is the case, expect frequent entrances into sleep mode to conserve battery power. During down time, the laptop should be connected to the AC Power adapter so that the battery will be replenished for the next operational cycle. To use the AC Power Adapter, align the DC Icons on the Adapter and on the port (on the right side of the Laptop) and slide in to connect and then plug in the other end of the Adapter to US AC Power (117 V rms) or to the UPS. The green LED on the Adapter AC to DC Transformer should illuminate and the battery icon on the laptop front panel should also illuminate.

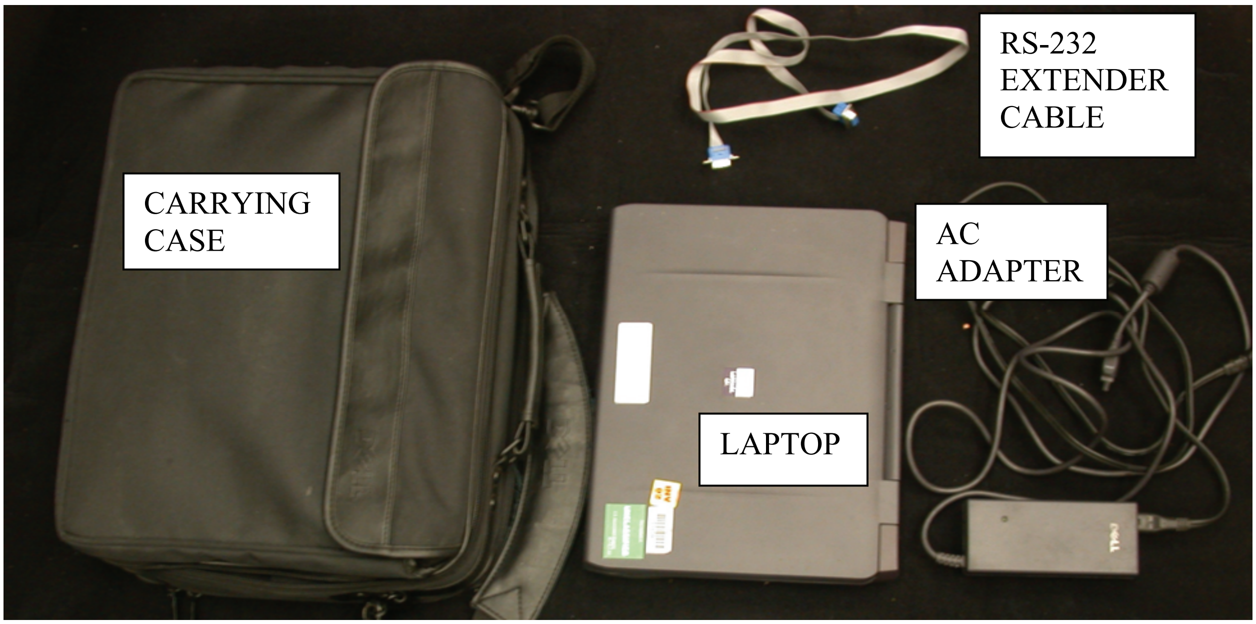


Figure 9. Remote station laptop critical items.

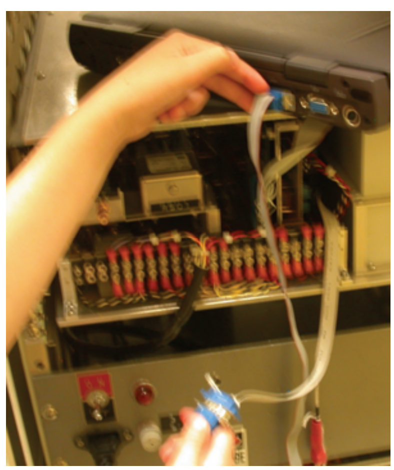

Figure 10. RS-232 interface attachment.

Press the Power Button on the Laptop Front panel (to the left above the keyboard). The power LED should illuminate on the Laptop and Windows 98 should load ending with the Guest Login screen. Click OK to login as guest (no password is needed). Click CLOSE if an "Old Virus Definition File" Dialog Box appears. Figure 11 is a screenshot of the Desktop which should be displayed.


Figure 11. Screenshot of RS laptop desktop.

Double click the Full Control VI as highlighted in figure 11. This is a National Instruments Lab View Run Time Executable file and will launch the compiled Virtual Instrument (VI) as shown in figure 12. There are a number of controls present, however, only the Doppler frequency offset ($f_d$) control will be used. As with all Vis, the first step is to start the VI by clicking on the white Run arrow in the upper left corner of figure 12. Next click the DDS_FREQUENCY Tab as highlighted in figure 12. The resulting Display is shown in figure 13.

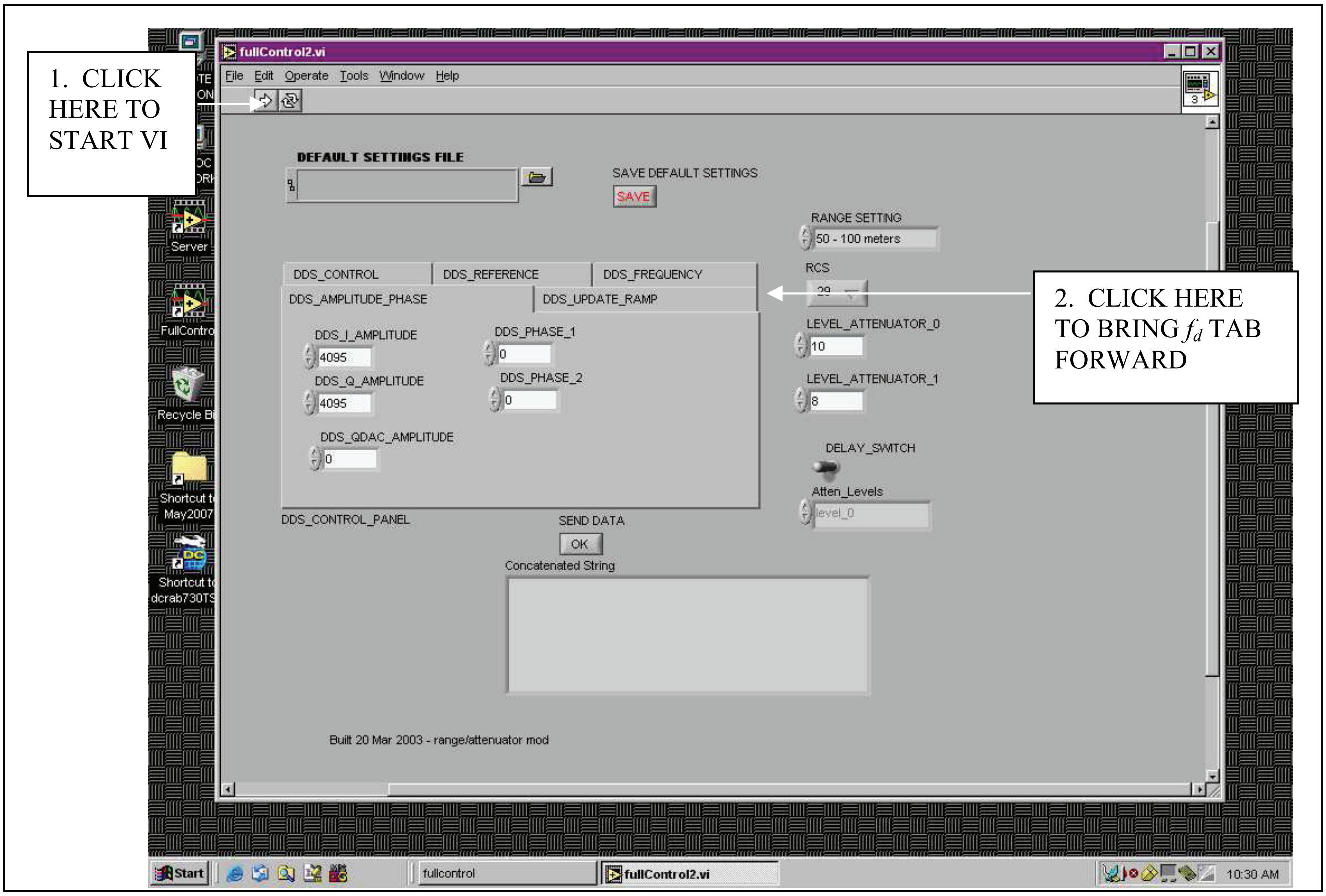


Figure 12. Screenshot of full control VI.

In the DDS_FREQ1 Box (highlighted in figure 13), enter the desired Doppler Frequency offset in Hertz. For example, enter "200" for 200 Hz, "1000" for 1 kHz or "3000" for 3 kHz. The acceptable range is 0 to 1000000 (1 MHz). Be sure to press the ENTER key after typing in the desired value. Next click the OK button under the SEND DATA text. Note that (1) you should hear clicking sounds as the configuration commands are sent by the SBC to switches and variable attenuators (not currently in use) and (2) the data string is updated as shown in figure 13 reflecting the desired value of $f_d$. If for some reason, the AC power fluctuates enough, the SBC will reset to a default value with no indication to the user that this has occurred. Furthermore, the VI will be hung up and will not be able to send data (even though the Concatenated String field shown in figure 13 will update, the message traffic is NOT being transmitted). To rectify this situation, depress the red reset switch shown in figure 6(b) and you will hear a click. Data can now be sent normally by clicking OK under the SEND DATA text.

The other parameter to set is the simulated RCS. As discussed in the preceding section, simply rotate the knob on the RCS Attenuator (AT3) on the aiming plate to the desired value of attenuation corresponding to the desired value of simulated RCS. As mentioned above, the attenuation values are only calibrated for those areas within the readout range (0 to 50 dB) with less precision as attenuation values increase.

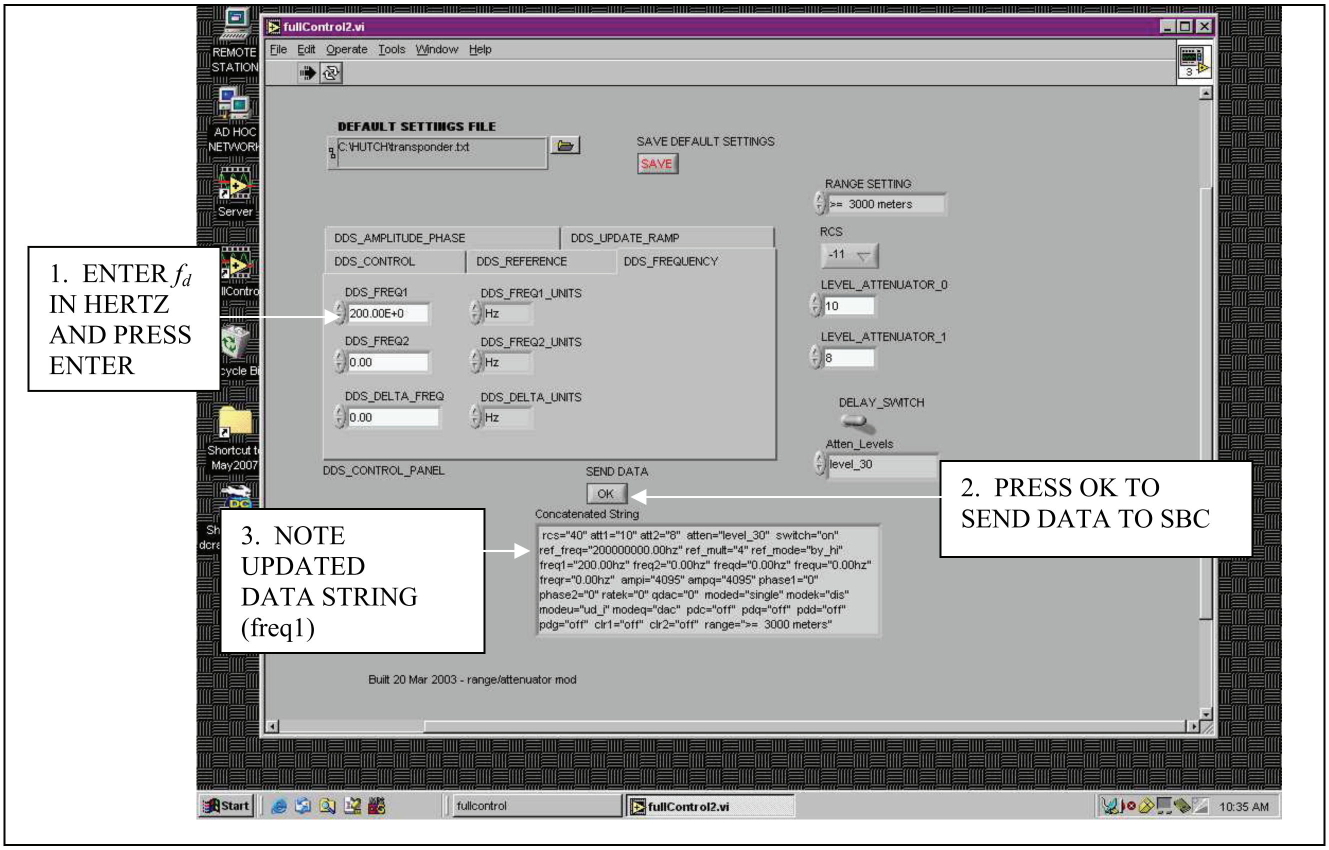


Figure 13. Screenshot of $f_d$ setting sent to SBC (and DDS).

At this point the RS is completely configured and operational. To change simulated RCS change the attenuation value as described in the preceding section. To change $f_d$, repeat the process shown in figure 13 making sure to (1) press ENTER in Step 1 and (2) Press OK as in Step 2. Again, if it appears that this process is not working, reset the SBC by pressing the reset switch and retry the data transmission.

The RS may be operated in all conditions including precipitation provided the power supplies are protected from liquid accumulation sufficient to short out the voltage lines. The use of a plastic wrap to protect the power supplies on the front of the RS chassis as well as the terminal blocks on the rear of the RS chassis and on the aiming plate and on all exposed voltage terminals of active elements (i.e., amplifiers on the aiming plate) is strongly recommended. If the power supplies detect a short condition, protection circuitry will current (and thus voltage) limit the output such that the RS will effectively shut down.

To shut down the RS, simply turn off the AC Power Switch. The laptop should be Shut-Down following standard Windows shut down procedures. Make sure to press the power button on UPS (turn off) or the battery on the UPS will deplete when the AC Power source (generator) is switched off. The laptop, aiming plate and UPS may be stored on the laptop deck shown in figure 6 and the doors reattached which provides a weatherproof container. This should only occur provided the RS is not to be transported. The coaxial connections between the aiming

plate and the RS chassis can not withstand the vibration environment associated with transportation.  If the RS is to be transported any distance, the aiming plate should be disconnected and the packed in its shipping crate.  The Laptop should be put away in its carrying case and the UPS should also be packed separately from the RS.

## Conclusion

A Millimeter Wave Transponder has been developed to simulate a moving target with the ability to alter RCS and Doppler frequency.  An explanation of the RF Architecture followed by a detailed derivation of Simulated RCS has been given.  Start to finish operating instructions are also provided.

# Appendix

## Measured RS Gain (data points for figure 3)

| (33 to 34 GHz) Frequency (GHz) | $\lvert S_{21}\rvert$ (dB) | (34 to 35 GHz) Frequency (GHz) | $\lvert S_{21}\rvert$ (dB) | (35 to 36 GHz) Frequency (GHz) | $\lvert S_{21}\rvert$ (dB) |
|---|---|---|---|---|---|
| 33 | 40.602 | 34.02 | 48.89 | 35.02 | 47.588 |
| 33.02 | 42.323 | 34.04 | 48.602 | 35.04 | 46.891 |
| 33.04 | 43.452 | 34.06 | 48.324 | 35.06 | 46.36 |
| 33.06 | 44.219 | 34.08 | 47.776 | 35.08 | 45.818 |
| 33.08 | 44.733 | 34.1 | 47.483 | 35.1 | 45.489 |
| 33.1 | 44.419 | 34.12 | 47.327 | 35.12 | 45.349 |
| 33.12 | 44.222 | 34.14 | 47.316 | 35.14 | 45.387 |
| 33.14 | 44.977 | 34.16 | 47.483 | 35.16 | 45.591 |
| 33.16 | 45.783 | 34.18 | 47.734 | 35.18 | 46.03 |
| 33.18 | 46.295 | 34.2 | 48.011 | 35.2 | 46.296 |
| 33.2 | 47.414 | 34.22 | 48.31 | 35.22 | 46.441 |
| 33.22 | 48.066 | 34.24 | 48.549 | 35.24 | 46.679 |
| 33.24 | 47.858 | 34.26 | 48.484 | 35.26 | 46.667 |
| 33.26 | 47.873 | 34.28 | 48.421 | 35.28 | 46.407 |
| 33.28 | 47.986 | 34.3 | 48.476 | 35.3 | 46.373 |
| 33.3 | 47.44 | 34.32 | 48.488 | 35.32 | 46.477 |
| 33.32 | 47.294 | 34.34 | 48.386 | 35.34 | 46.449 |
| 33.34 | 47.313 | 34.36 | 48.436 | 35.36 | 46.474 |
| 33.36 | 46.889 | 34.38 | 48.292 | 35.38 | 46.371 |
| 33.38 | 46.338 | 34.4 | 48.115 | 35.4 | 46.114 |
| 33.4 | 46.842 | 34.42 | 47.879 | 35.42 | 45.579 |
| 33.42 | 47.079 | 34.44 | 47.653 | 35.44 | 45.302 |
| 33.44 | 47.06 | 34.46 | 47.605 | 35.46 | 44.821 |
| 33.46 | 47.799 | 34.48 | 47.682 | 35.48 | 44.421 |
| 33.48 | 47.979 | 34.5 | 47.913 | 35.5 | 44.157 |
| 33.5 | 47.206 | 34.52 | 48.266 | 35.52 | 44.236 |

| Frequency (GHz) | $\lvert S_{21}\rvert$ (dB) | Frequency (GHz) | $\lvert S_{21}\rvert$ (dB) | Frequency (GHz) | $\lvert S_{21}\rvert$ (dB) |
|---|---|---|---|---|---|
| 33.54 | 46.416 | 34.56 | 49.324 | 35.56 | 44.677 |
| 33.5575 | 45.761 | 34.58 | 49.637 | 35.58 | 45.338 |
| 33.58 | 45.527 | 34.6 | 49.896 | 35.6 | 45.95 |
| 33.6 | 46.197 | 34.62 | 49.866 | 35.62 | 46.561 |
| 33.62 | 46.605 | 34.64 | 49.792 | 35.64 | 46.942 |
| 33.64 | 47.181 | 34.66 | 49.498 | 35.66 | 47.176 |
| 33.66 | 48.345 | 34.68 | 49.244 | 35.68 | 47.023 |
| 33.68 | 48.954 | 34.7 | 48.828 | 35.7 | 46.801 |
| 33.7 | 49.123 | 34.72 | 48.662 | 35.72 | 46.712 |
| 33.72 | 49.462 | 34.74 | 48.413 | 35.74 | 46.658 |
| 33.74 | 49.517 | 34.76 | 48.188 | 35.76 | 46.551 |
| 33.76 | 49.294 | 34.78 | 47.779 | 35.78 | 46.555 |

| | | | | | |
|---|---|---|---|---|---|
| 33.78 | 49.215 | 34.8 | 47.509 | 35.8 | 46.489 |
| 33.8 | 49.386 | 34.82 | 47.224 | 35.82 | 46.358 |
| 33.82 | 49.015 | 34.84 | 46.948 | 35.84 | 46.187 |
| 33.84 | 48.701 | 34.86 | 46.863 | 35.86 | 46.073 |
| 33.86 | 48.426 | 34.88 | 46.929 | 35.88 | 45.885 |
| 33.88 | 48.178 | 34.9 | 47.072 | 35.9 | 45.908 |
| 33.9 | 47.769 | 34.92 | 47.344 | 35.92 | 45.922 |
| 33.92 | 47.839 | 34.94 | 47.623 | 35.94 | 45.992 |
| 33.94 | 47.953 | 34.96 | 48.039 | 35.96 | 46.175 |
| 33.96 | 48.117 | 34.98 | 48.087 | 35.98 | 46.541 |
| 33.98 | 48.552 | 35 | 47.995 | 36 | 46.582 |
| 34 | 48.937 | | | | |

**(36 to 37 GHz)**

| Frequency (GHz) | \|S21\| (dB) | Frequency (GHz) | \|S21\| (dB) | Frequency (GHz) | \|S21\| (dB) |
|---|---|---|---|---|---|
| 36.02 | 46.653 | 36.42 | 46.254 | 36.8 | 39.812 |
| 36.04 | 46.245 | 36.44 | 45.67 | 36.82 | 36.599 |
| 36.06 | 45.737 | 36.46 | 45.442 | 36.84 | 33.527 |
| 36.08 | 45.119 | 36.48 | 45.542 | 36.86 | 30.843 |
| 36.1 | 44.741 | 36.5 | 45.717 | 36.88 | 28.407 |
| 36.12 | 44.39 | 36.52 | 45.947 | 36.9 | 26.12 |
| 36.14 | 44.37 | 36.54 | 46.448 | 36.92 | 24.11 |
| 36.16 | 44.453 | 36.56 | 46.882 | 36.94 | 22.31 |
| 36.18 | 44.707 | 36.58 | 47.178 | 36.96 | 20.589 |
| 36.2 | 45.021 | 36.6 | 47.138 | 36.98 | 18.966 |
| 36.22 | 45.405 | 36.62 | 46.802 | 37 | 17.345 |
| 36.24 | 45.463 | 36.64 | 46.219 | | |
| 36.26 | 45.634 | 36.66 | 45.765 | | |
| 36.28 | 45.928 | 36.68 | 45.531 | | |
| 36.3 | 46.253 | 36.7 | 45.423 | | |
| 36.32 | 46.454 | 36.72 | 45.448 | | |
| 36.36 | 47.083 | 36.74 | 45.768 | | |
| 36.38 | 46.925 | 36.76 | 44.799 | | |
| 36.4 | 46.632 | 36.78 | 42.741 | | |

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